

Die Zukunft der Hochtemperatur-Elektrolyse

Dr. Zacharie Wullemin

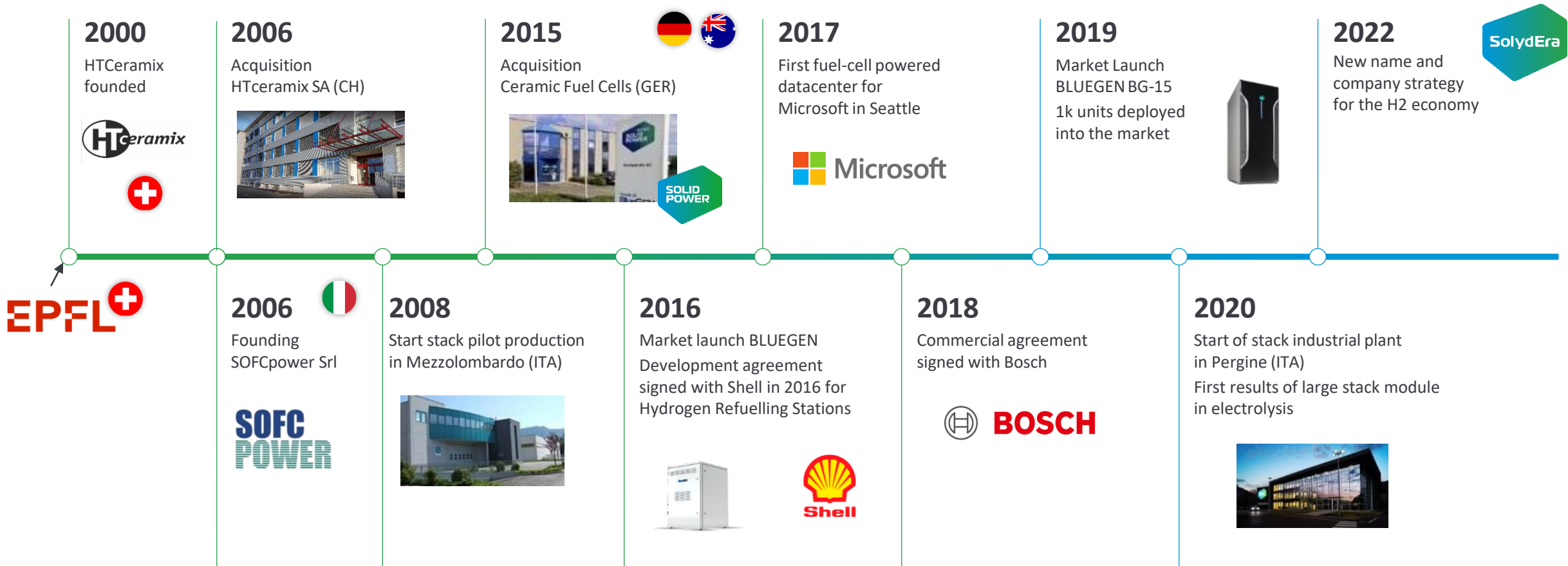
Team Leader – Technology Development & Application Engineering

SolydEra SA, Yverdon-les-Bains, Switzerland



We stack it.

SolydEra - More than 20 years of experience in SOC technology



SolydEra at a glance

Products

vertically integrated end-to-end fuel cell technology provider
ready to enter green hydrogen production



Stack

Stack
Module

Fuel Cell
module

System

Partners & Affiliations



BOSCH



EQUINIX



Group structure



HEINSBERG
GERMANY

Assembling



MEZZOLOMBARDO
ITALY

R&D, Pilot
Production



PERGINE VALSUGANA
ITALY

Stack Manufacturing,
Head Quarters



YVERDON
SWITZERLAND

R&D Center



MELBOURNE
AUSTRALIA

R&D Center

Facts & figures

3,000
units
installed

250+
customers

90 GWh
energy
produced

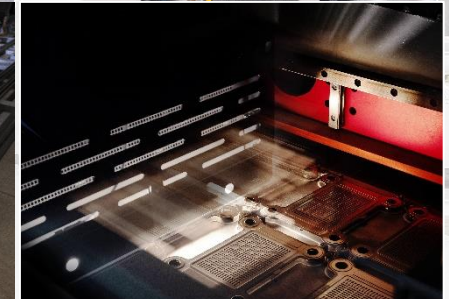
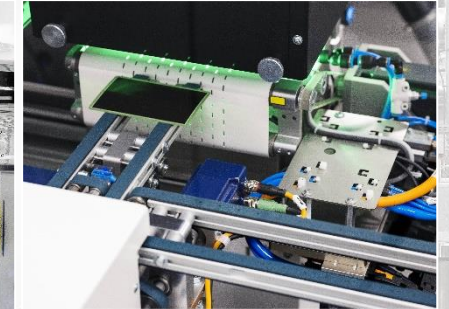
Products
sales in 22
countries

75M
hours of
operation



Europe's largest industrial production plant for SOFC stacks

AUTOMATED STACK MANUFACTURING PLANT



25 MW
on 2 shifts



1mn
cells/year



60
stacks/day

One stack – multiple applications



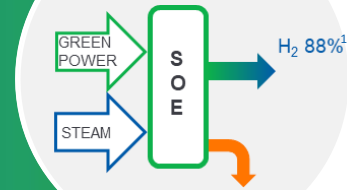
GAS-TO-POWER

High efficiency Power and Heat production by using multiple fuels, including natural gas, H₂ and H₂/gas blends



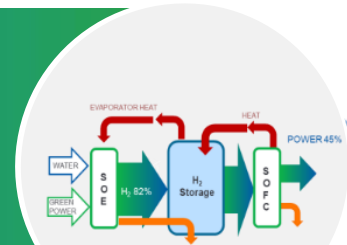
POWER-TO-GAS

Conversion of steam into H₂ by using electricity for hard-to-abate industrial sectors and transportation



POWER-TO-POWER

Reversible SOFC systems integrated with H₂ storage in order to decouple electricity production and use



Applications

Industrial solutions

Integration of stacks for electrolysis and industrial sectors (*e.g.* green steel, synthetic fuel, marine sector, chemical industry)

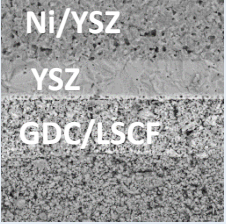
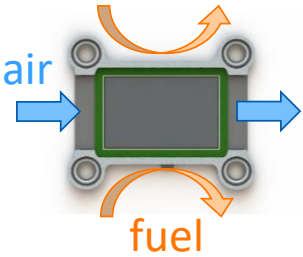

Professional solutions

Integration of fuel cell modules into technical solutions of professional integrators (*e.g.* data centres)

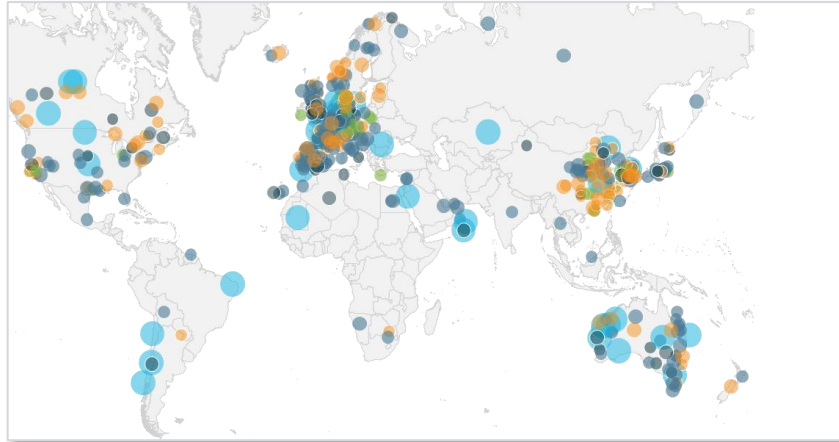
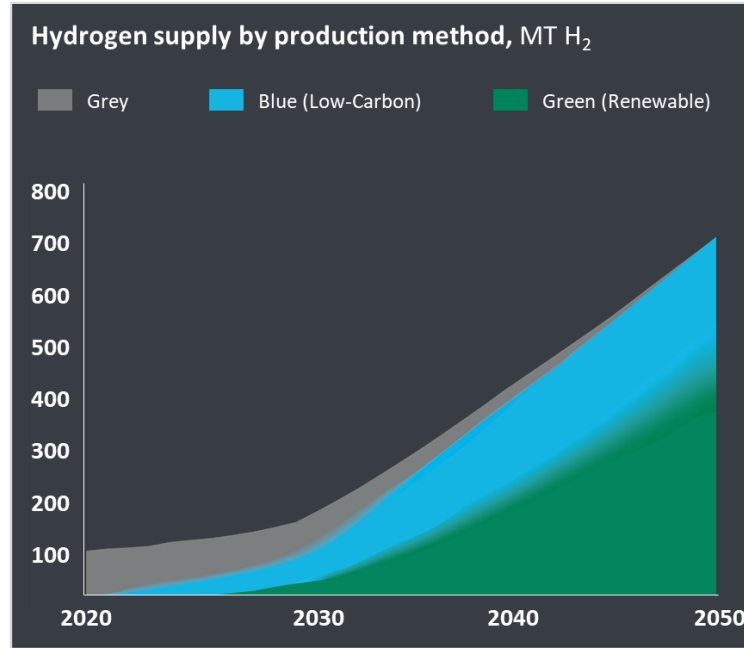
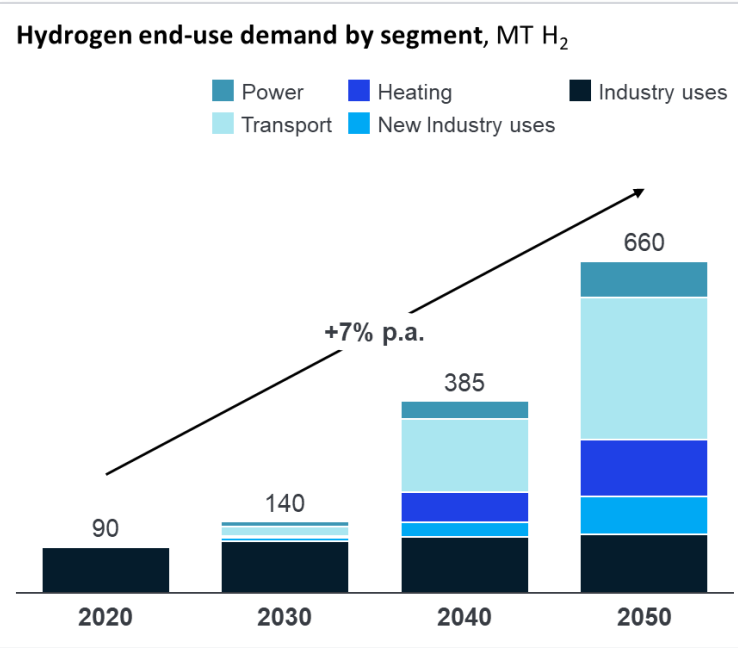
Commercial solutions

Sales of power generators and co-generators to commercial customers (residential, retail, hospitality, offices, transport)

A SOLID stack technology

| | | |
|----------------------|---|--|
| TECHNOLOGY |  | <ul style="list-style-type: none">• planar anode supported cells with a very thin electrolyte, allows operation in a wide temperature range (650-800°C)• Proprietary sealing material for tightness & robustness• Optimized interconnect coatings for extended lifetime |
| STACK DESIGN |  | <ul style="list-style-type: none">• Proprietary parallel flow design for optimal temperature distribution, maximum stack lifetime and robustness• Interconnect produced by standard automotive manufacturing process• Uniform and stable fuel electrode geometry for high Fuel Utilization and Steam Conversion |
| TRACK RECORDS |  | <ul style="list-style-type: none">• Proven operation in SOFC, SOE, co-electrolysis and reversible mode• Stack efficiency up to 75% in SOFC (2015) and 97% in steam electrolysis (2020)• Average 0.2% efficiency drop per 1'000 h in the field• 8 kW stack in a single tower (25 kW in SOE) |

Hydrogen is crucial to achieve decarbonization targets



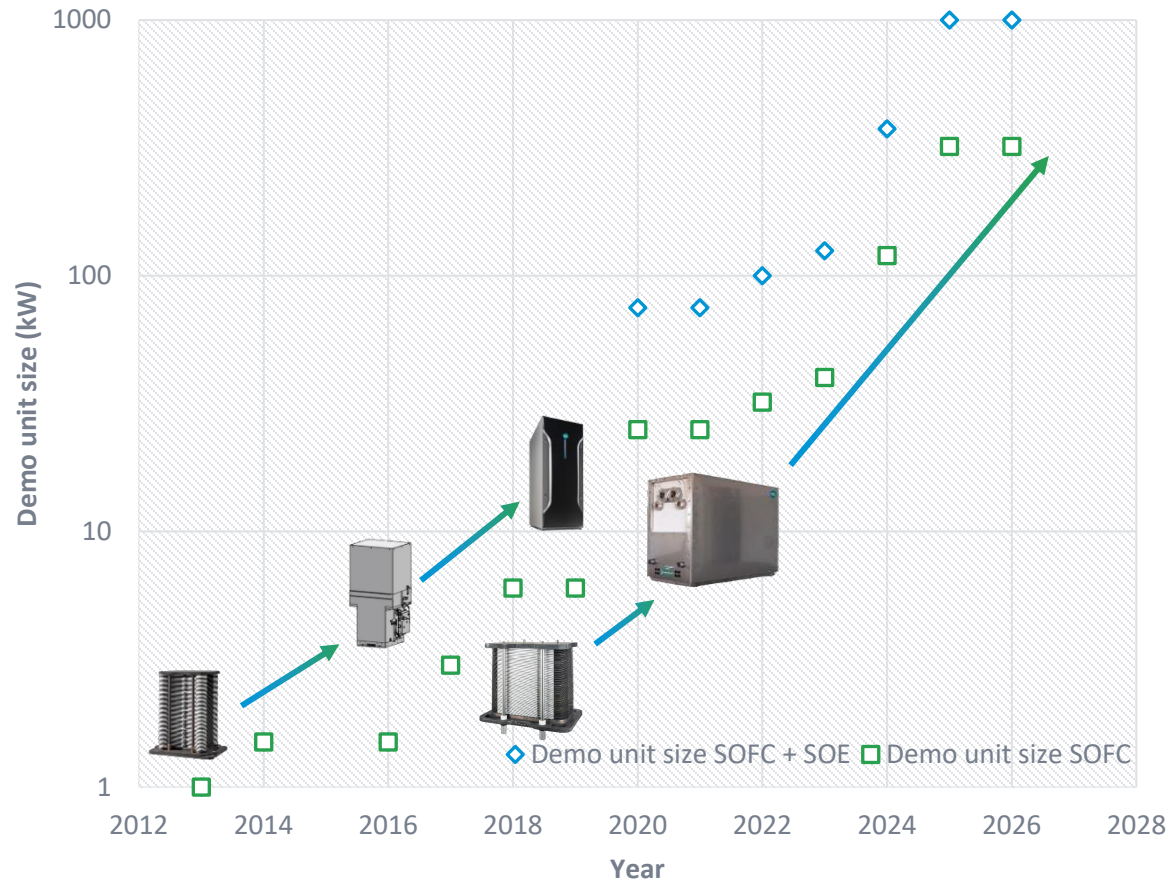
Hydrogen role in energy transition

- H₂ is complementary to batteries and the only solution to decarb **hard-to-abate industrial sectors** and **heavy-duty transportation**
- **Green H₂ via electrolysis** is one the most promising technology available
- **100+ GW** capacity announced by 2030
- More than **500 projects** launched globally with **600+bn \$ investment**
- **SOE** will offer minimum electricity consumptions (**40 kWh/kg**) and reduced sensitivity to electricity price
- Capability to operate in **reversible mode** is opening further niche opportunities



**FUTURE SYSTEMS:
A QUANTUM STEP IN STACK AND MODULE SIZES**

DEVELOPMENT AT SOLYDERA - DEMONSTRATION UNIT SIZES



System size evolution

- Exponential size evolution since 2010
- Residential CHP and industrial applications
- Largest stack platform for the market
- Current module sizes
 - Electrolysis 125kW
 - Reversible 40/125kW
- Starting 2023: Preparation of multi-MW installations

A quantum step: the G8X stack and Large Stack Module

Large Stack Module 32 kW_e SOFC/100 kW_e SOE



SOFC – SOE Large Stack Module

- Based on the G8X stack
- 4 stacks tightly integrated in one single stackbox
- Common air and fuel supply
- One single interface to the system
- Fully instrumented

Main markets

- Power generation
- Cogeneration of power, heat and hydrogen (CH2P)
- Refueling stations
- Electrolysis, Power to X

Main specifications (Generation 2)

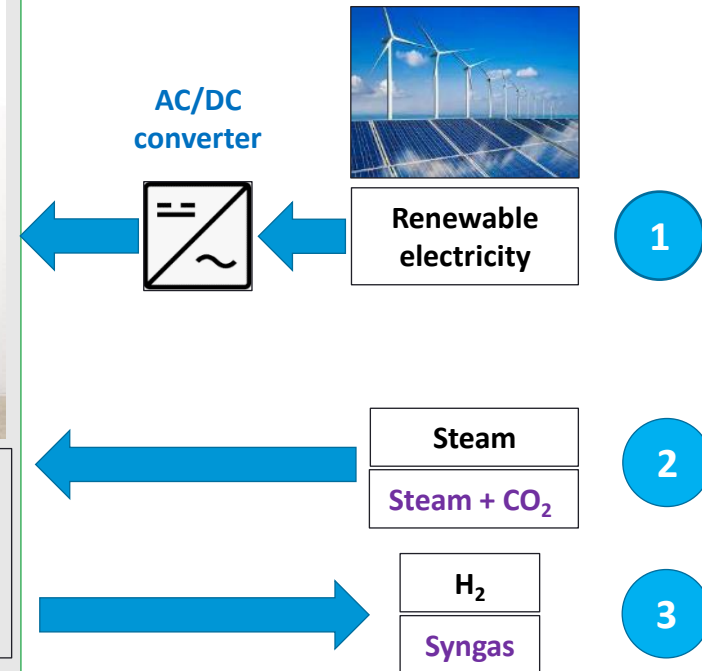
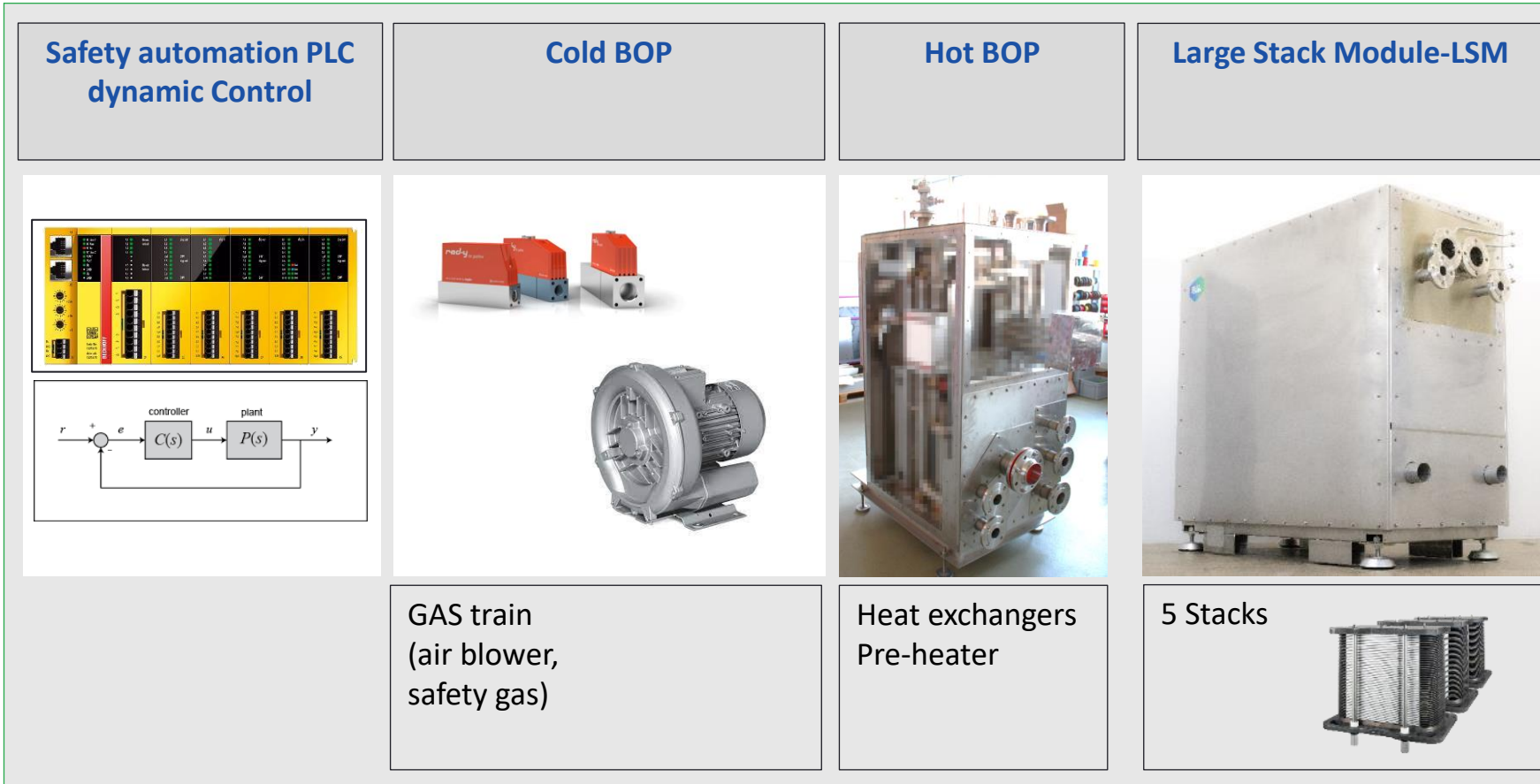
- Stack technology: G8
- 4 G8X stacks (8,3 kW nominal)
- Operation: SOFC and SOEC
 - SOFC: 32kW
 - SOEC: 65kg H₂ / day
- Electrical power: – 100kW .. +32kW
- Individual polarization control on 4 stacks
- Fuel and air supply:
 - Common for the 4 stacks
 - Fuel supply deviation < 1%
- Fuel: H₂, Natural gas, syngas, steam, others
- Heat-up < 24h
- Nominal operating temperature 680-800°C
- Heat losses: 1.5-1.8kW (measured)
- Dimensions: 1.7 x 0.85 x 1.65 m



**FUTURE SYSTEMS:
REVERSIBLE OR PURE ELECTROLYSIS ?**

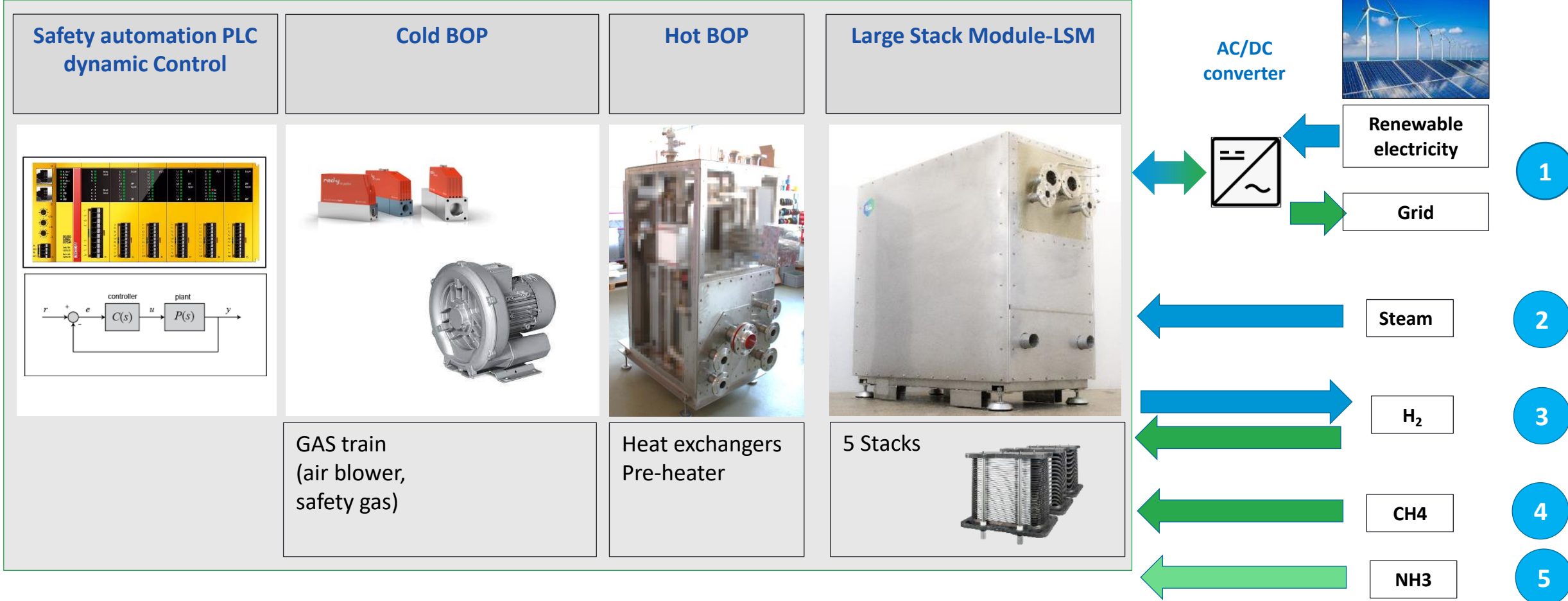
ECM – Electrolysis module

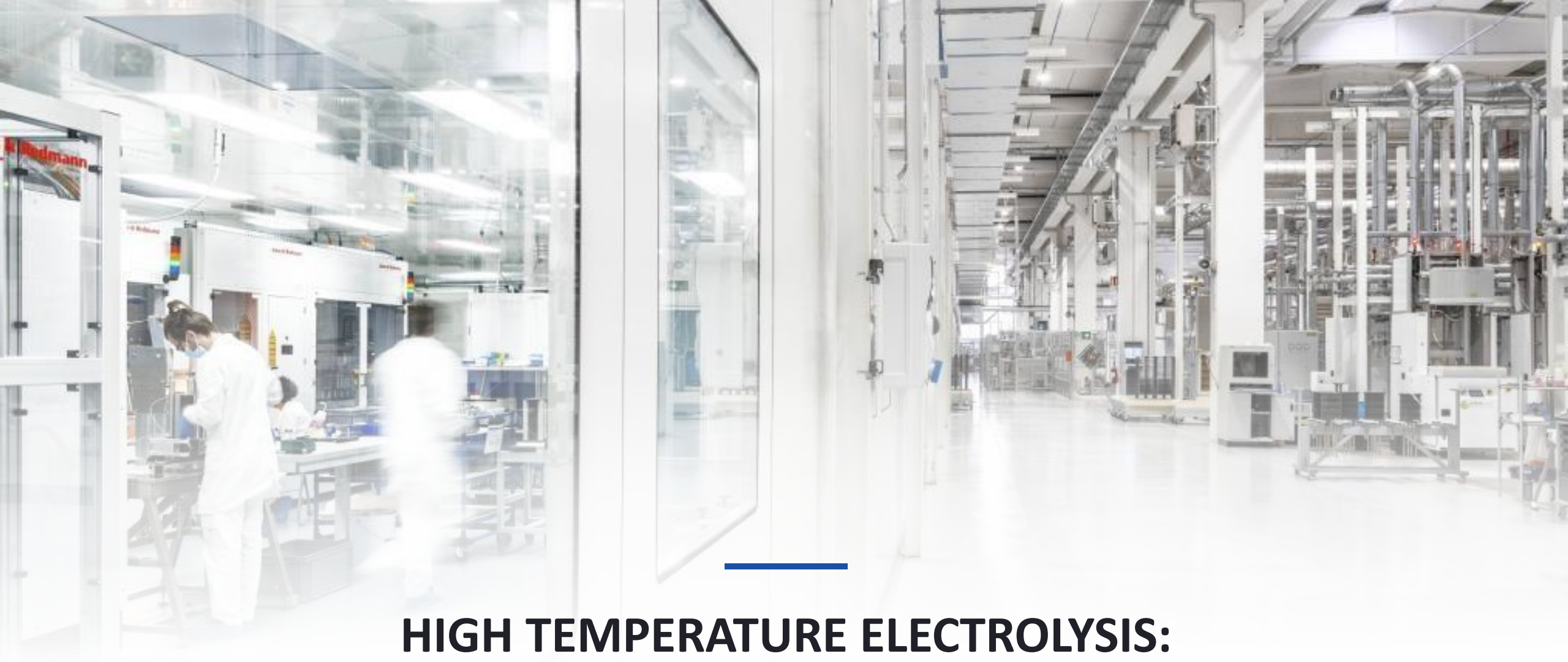
ECM125 Base unit



rSOC - Reversible module

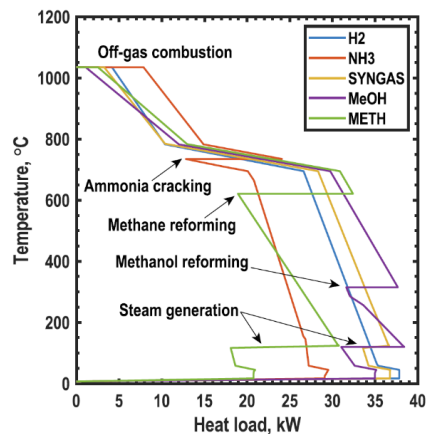
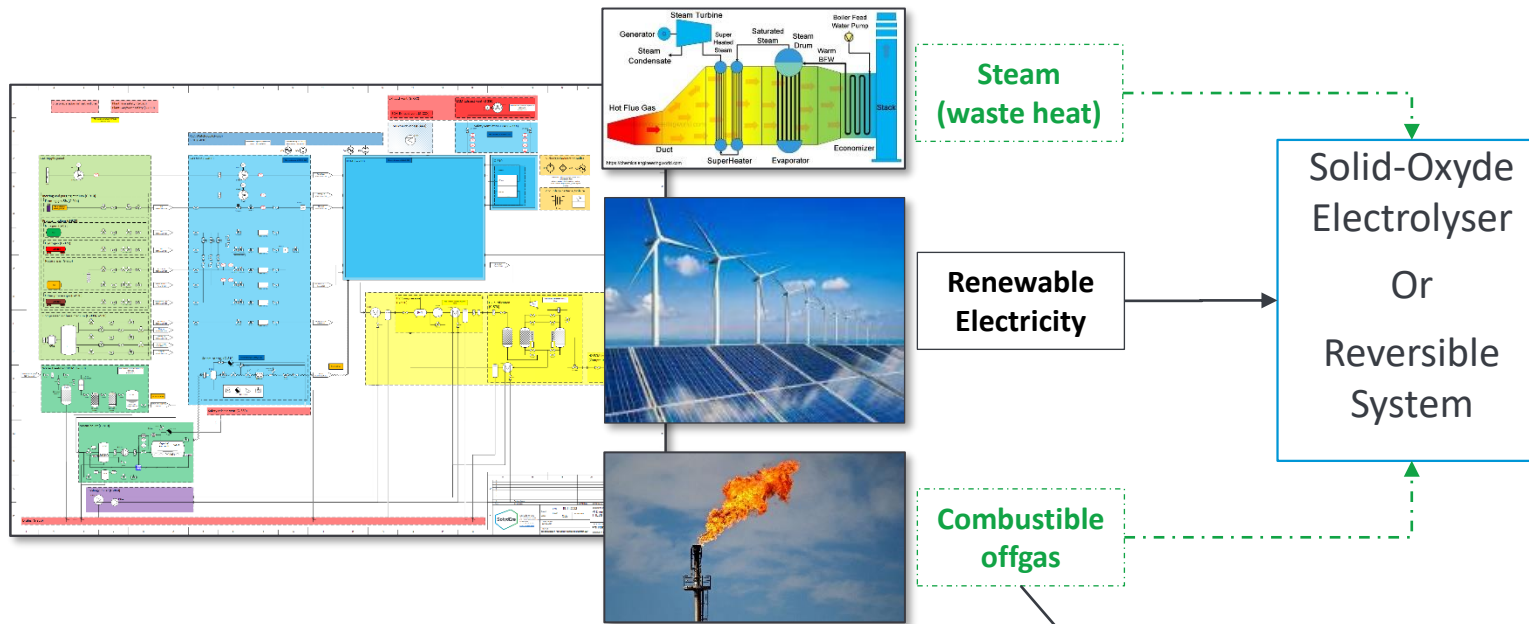
rSOC40/125 Base unit



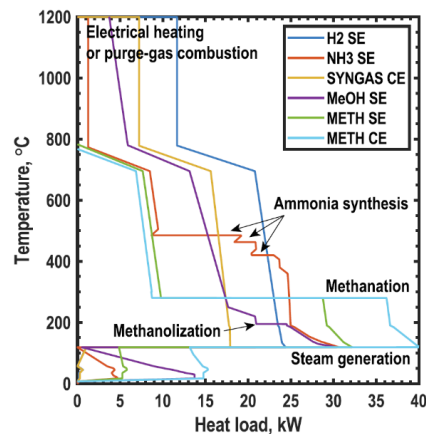


**HIGH TEMPERATURE ELECTROLYSIS:
MULTIPLE APPLICATIONS**

The key advantage of high-temperature electrolysis



(a) PowGen mode at 0.4 A/cm^2



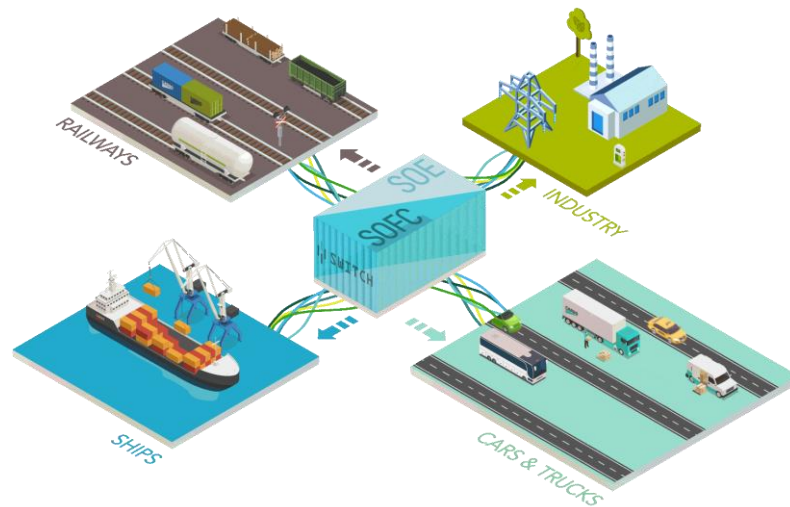
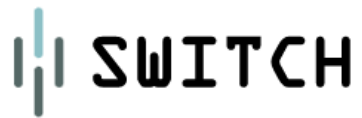
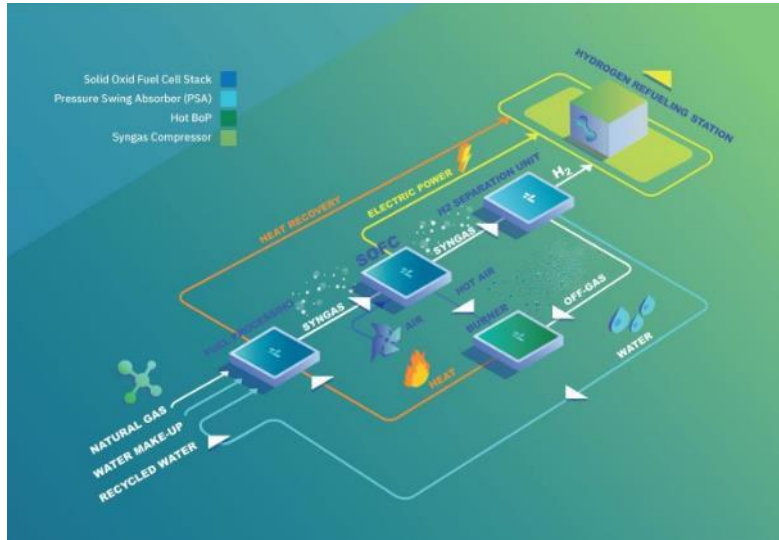
(b) PowSto mode at 0.7 A/cm^2

Fig. 7. Heat integration comparison with the stack working at atmospheric pressure.

- **Favorable thermodynamics**
 - Electrolysis of steam is more efficient than electrolysis of water
 - Energy consumption **34.6kWh/kg** at stack level (thermoneutral conditions)
- **Valorization of synergies with the customer's plant**
 - **Waste heat:** used for the preparation of steam
 - **Waste offgas:** used for heating or for reversible operation and standby
 - **Local production and use of hydrogen**
- **Low energy consumption**
 - Fully electric (incl steam): 48 kWh/kg
 - Using steam from plant: 40 kWh/kg
 - Exploiting offgas: 37kWh/kg
 - **Stack only (DC): 35kWh/kg**

**Forecasted values from experimental and modeling work, experimental proof to come soon*

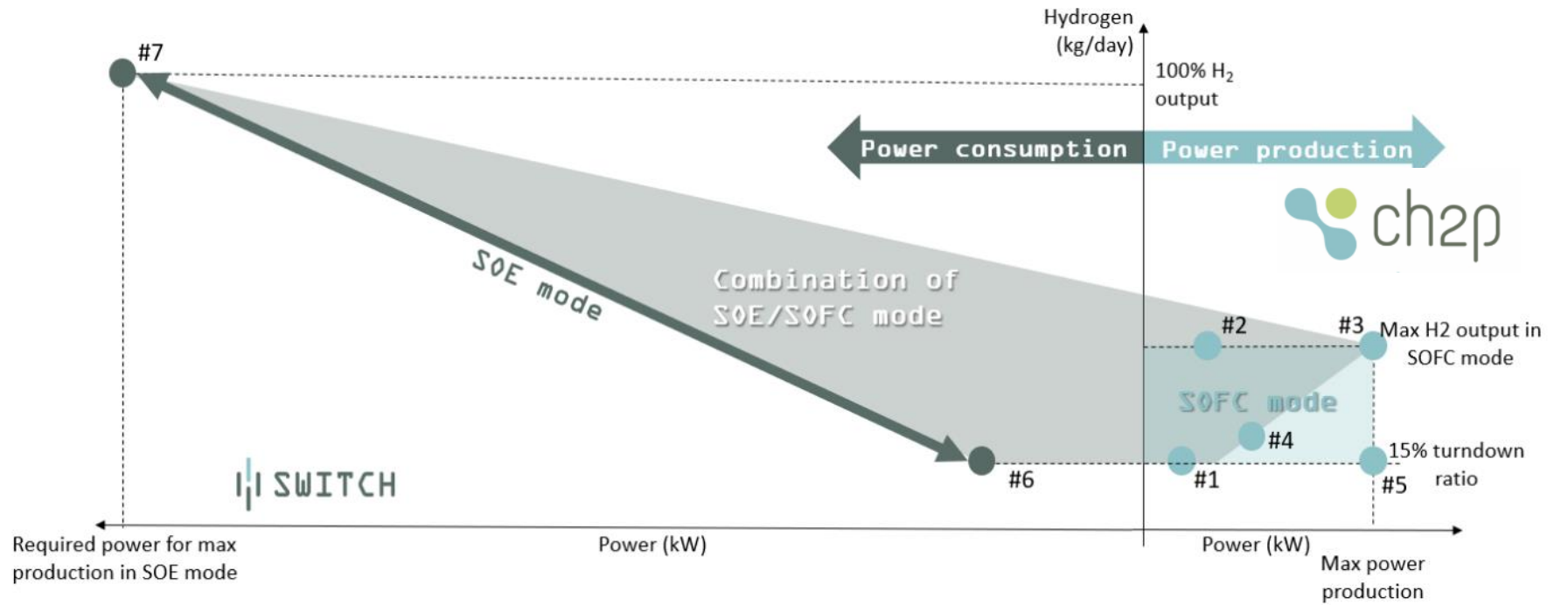
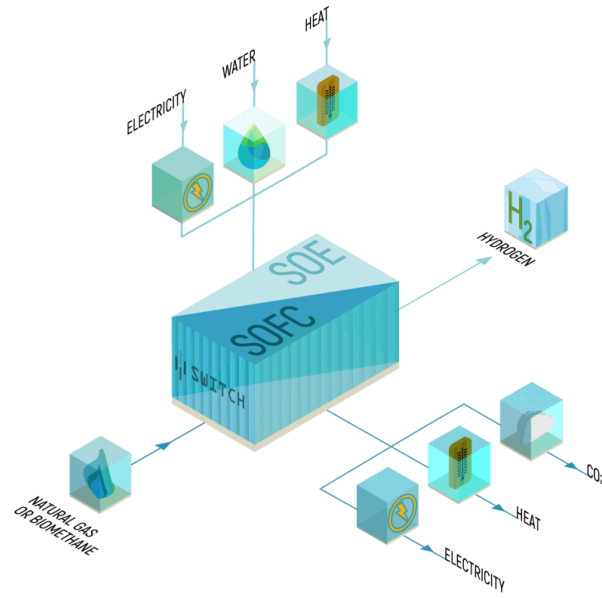
DECENTRALIZED, REVERSIBLE HYDROGEN (CO-)GENERATION



System design

- Main target: H2 refuelling stations
- Operation modes:
 - Hydrogen co-generation from NG/Biogas (CH2P)
 - Steam Electrolysis (SWITCH)
- Technology: coupling of a (reversible) SOFC system with a PSA unit for gas cleaning
- Module specifications
 - **One single module** for 2 operation modes
 - **Hydrogen co-generation mode (CH2P):** production of 20kg H2/day + 25kWel
 - **SOE mode (SWITCH project):** min 50kg H2/day

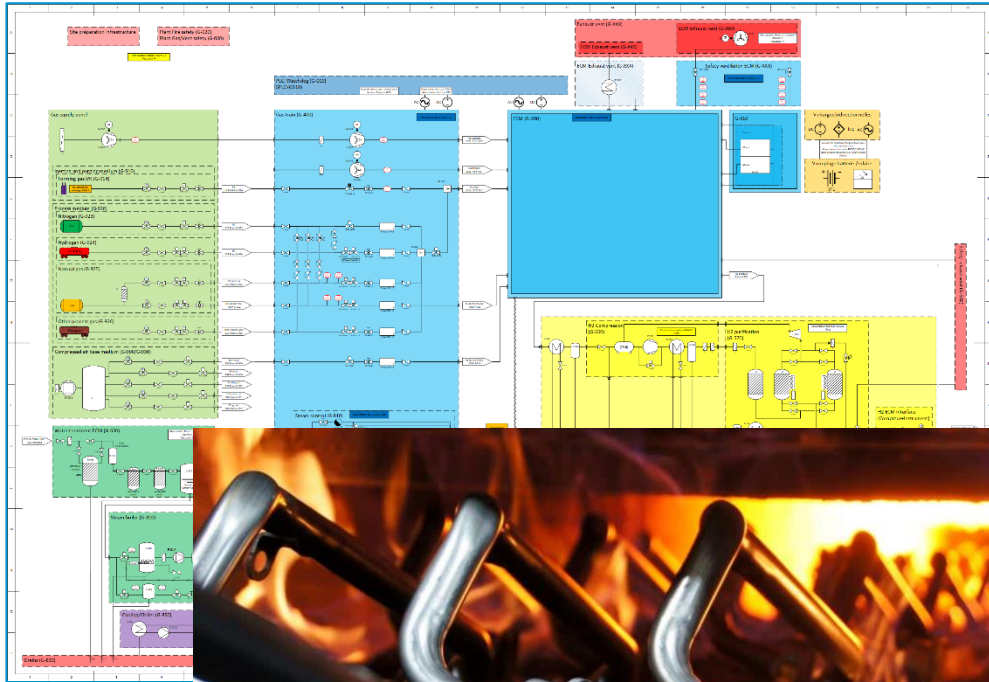
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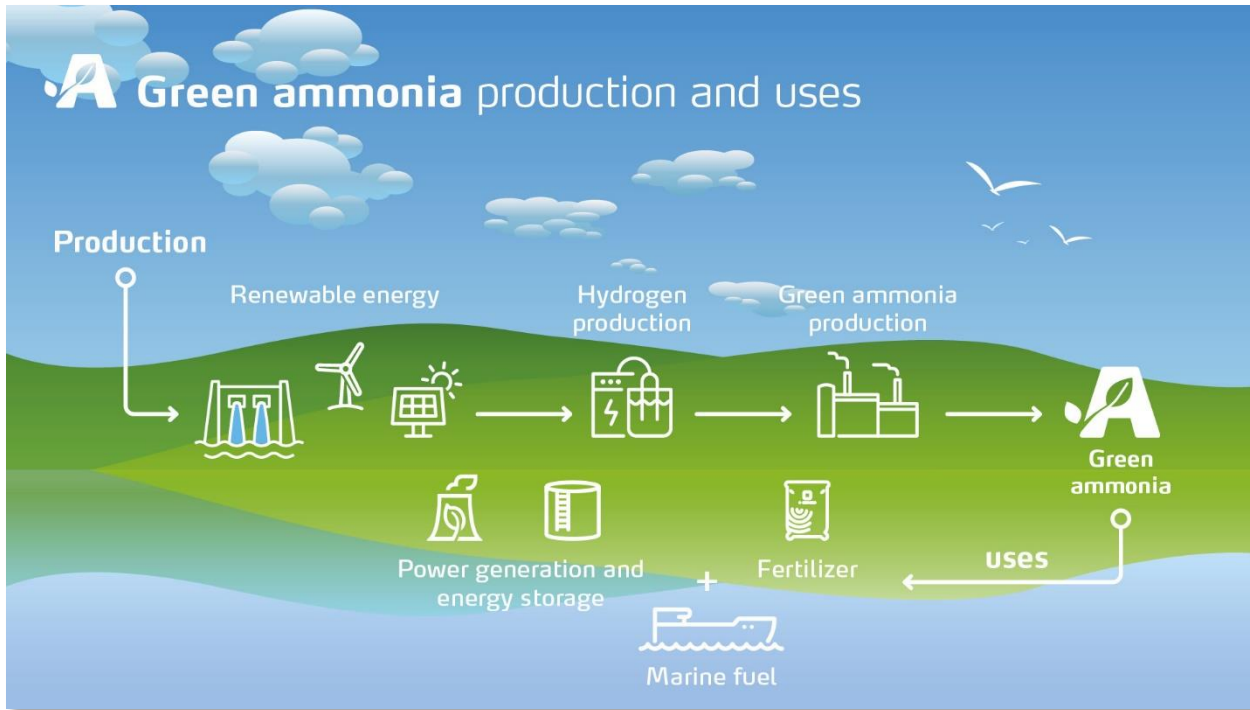
ELECTROLYSIS FOR GREEN STEEL AND METALLURGY



Overview

- Hydrogen for metal reduction or protective atmosphere (Heat treatment furnaces, welding, etc.)
- Opportunities for SOE
 - Heat recovery (free steam)
 - Process offgas
 - Renewable electricity / plant generators
- Current project in elaboration
 - Customer: Swiss Utility
 - End-user: Swiss steel manufacturer
 - In-field testing of the ECM100 / ECM125
 - Full-integration test with H₂ purification
 - Plant integration
 - Coupling with solar field & battery storage

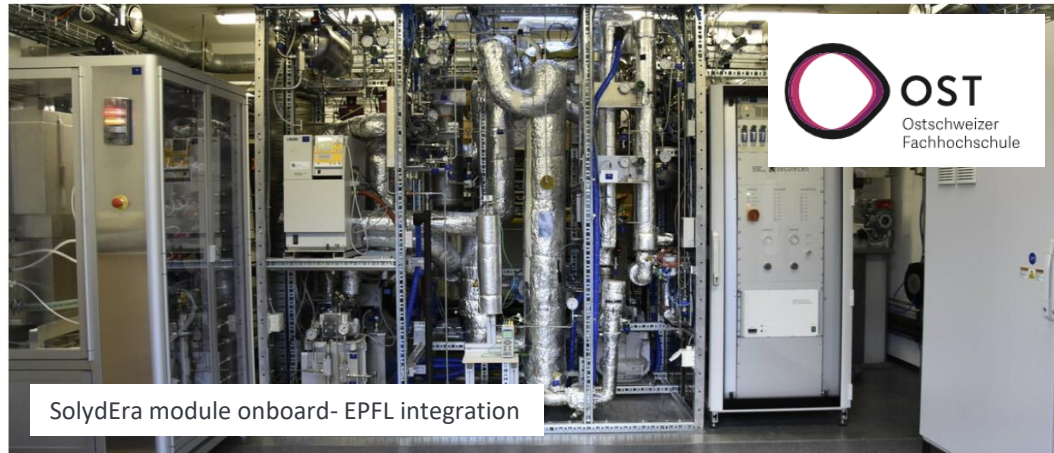
ELECTROLYSIS FOR GREEN AMMONIA



Overview

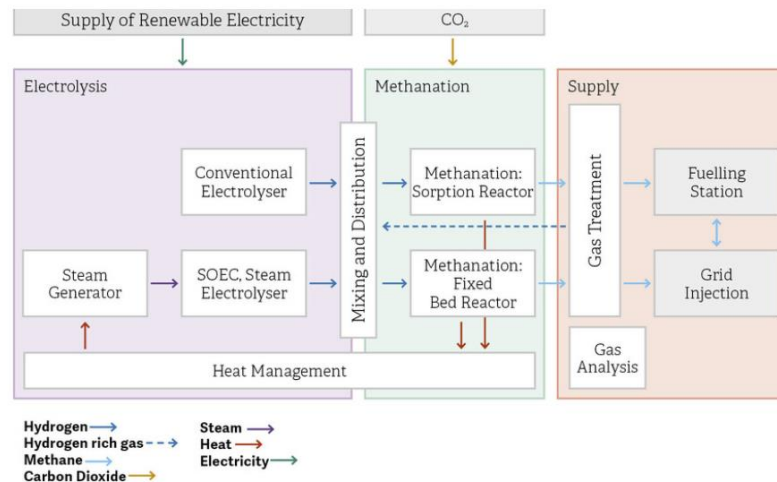
- Hydrogen for green ammonia production
- Opportunities for SOE
 - Heat recovery (free steam)
 - Process offgas
 - Large solar & renewable fields / onsite power generation
- Current project in elaboration
 - Customer: confidential
 - End-user: confidential
 - Multi-MW projects

ELECTROLYSIS FOR SYNTHETIC FUELS



SolydEra module onboard- EPFL integration

Demonstrationsanlage HEPP High Efficiency Power-to-Methane Pilot

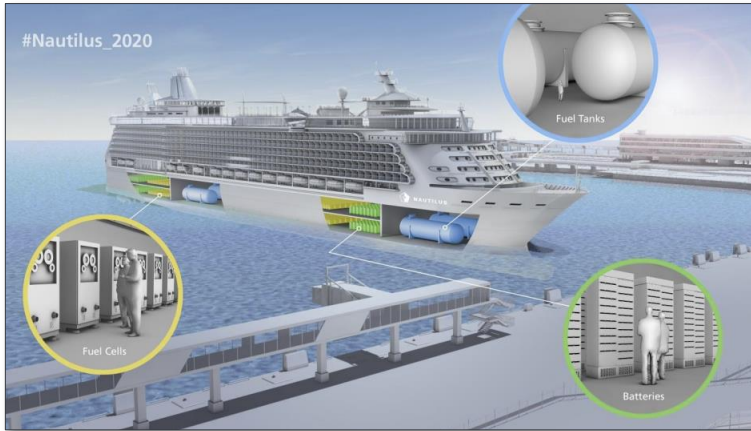


Blockflussdiagramm der Power-to-Methane-Versuchsanlage in Rapperswil mit den relevanten Komponenten

Overview

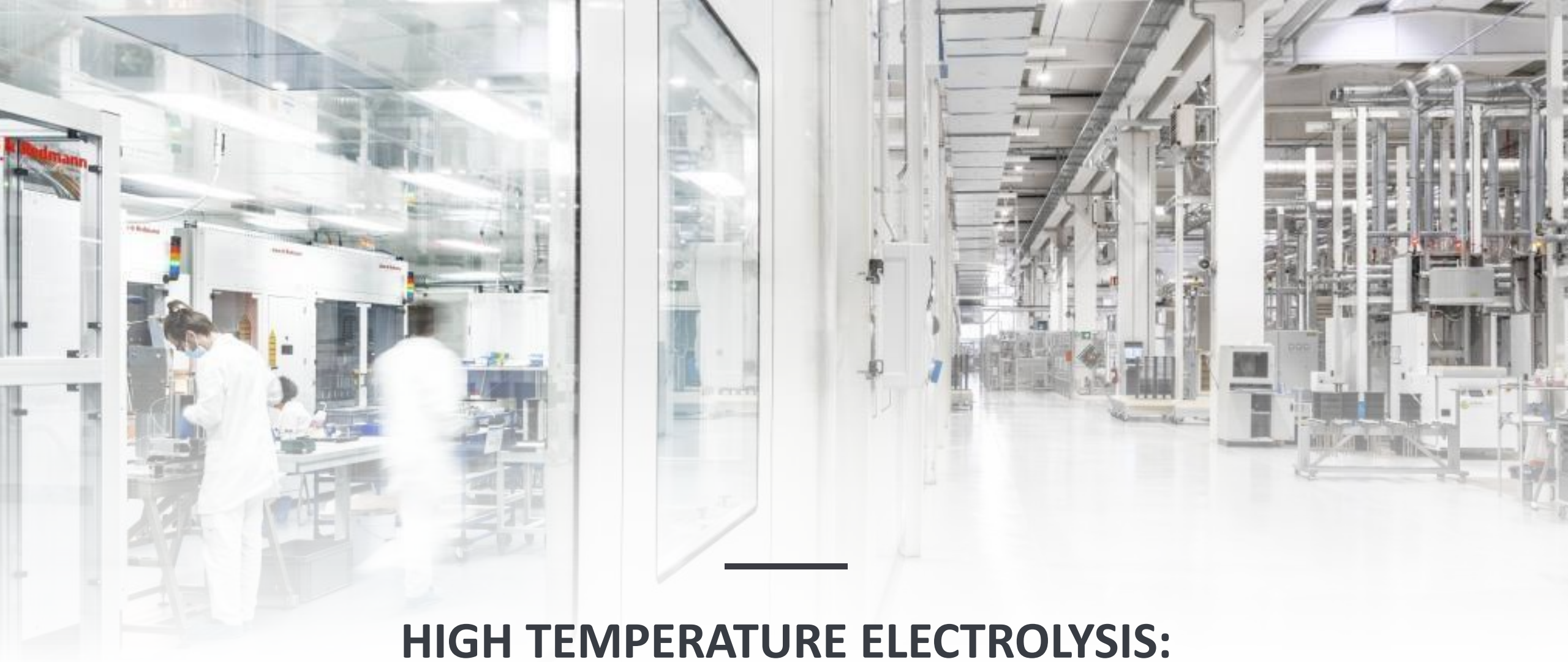
- Hydrogen for synthetic fuel production
- Opportunities for SOE
 - Heat recovery e.g from methanation process
 - Process offgas (e.g. cleaning offgas)
 - Renewable electricity
- Current projects
 - OST demonstration unit
 - Others (various sizes):
 - Biomass treatment plant
 - Methanation
 - Methanolization

OTHER APPLICATIONS OF THE SOLID OXIDE TECHNOLOGY



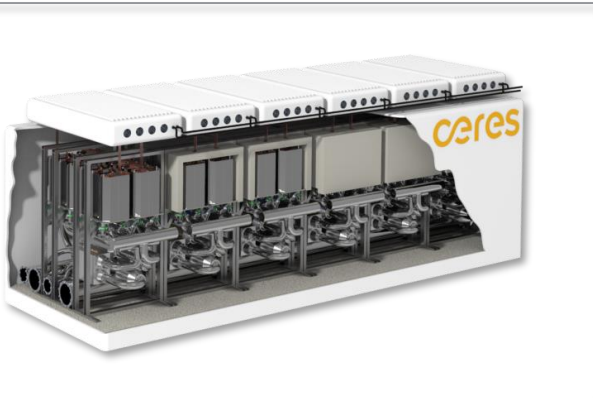
Overview

- Naval industry
 - Hotel power generation
 - Propulsion
 - UPS
- Datacenter
 - High-availability power generators
- Grid services (reversible systems)
 - Power-to-Gas
 - Gas-to-Power (different sources)
- Etc.



**HIGH TEMPERATURE ELECTROLYSIS:
PROJECTS WORLDWIDE**

THE KEY PLAYERS



- **Bloom Energy (US):**
 - Energy servers & Electrolysers
- **Sunfire (D)**
 - Multi-MW demo sites in SOE
 - Alkaline IHT Technology (CH)
- **SolydEra (I,CH,D,AUS)**
 - Proprietary stack and system technology
 - Reversible and pure SOE systems
 - Micro-COGEN units
- **Ceres / Shell – Bosch / Linde (D/UK)**
 - Ceres: SOE stack technology licensor
 - Demo projects 1MW -> Power-to-X
- **Halldor Topsoe (DK)**
 - Proprietary SOE technology e.g. for ammonia and syngas (proprietary)
- **Convion (FI)**
 - Integrator of Different stack technologies (Elcogen, IKTS, ...)
 - SOE and SOFC demonstrator
- **Genvia (F)**
 - Targeting Pink Hydrogen (Nuclear)?
- Other stack manufacturers: Elcogen, IKTS, etc

PROJECTS FOR THE NEXT YEARS & DECADES



Large-scale Green-Hydrogen Plants



European H2 network

• Decentralized Green Hydrogen

- Typical size < 100MW
- Blending in Natural Gas network
- Integration in Biogas/Biomass/Waste treatment
- Reversible systems
- Steel manufacturing, etc

• Large Green-Hydrogen Plants

- Typically > 500MW – 2GW
- Solar and/or wind power on site
- Multi-technologie Alkaline + PEM + SOE
- Main sites:
 - **Middle East:** > 100GW solar fields
 - Technology:
 - Industry integration: e-NG, green ammonia
 - **South US**
 - **South Europe (Portugal, Greece)**
 - E.g. White Dragon: 250.000 T/y H2
 - **North Europe:** e.g. Liquid Wind (wind to methanol)
 - Industry: e-fuels, paper industry
 - **Asia** (Japan, South Korea, China,..)
 - **South America** (Chile, etc.)
- Main challenges
 - Manufacturing and financial capacity of suppliers
 - Materials (e.g. Iridium for PEM)
 - Power electronics
 - Intermittent renewable energy
 - On-site storage

Networks and hydrogen carriers: an open question

Conclusion



- High temperature electrolysis has an important role to play in the future of decarbonization
- The technology maximizes the synergies with the customer's process
- SolydEra acts as a **core technology provider**, offering stacks and electrolyzer modules to system integrators and EPC partners
- H2 production by electrolysis with **< 40 kWh/kg** and potential H2 cost **< 1.5 \$/kg**
- Fully **reversible technology**: the same asset can generate electricity from H2 when needed, enabling coupling with solar and wind green energy sources
- CO₂/steam **co-electrolysis possible** to produce syngas, the base for e-fuel production

THE
FUTURE
IS NOW

